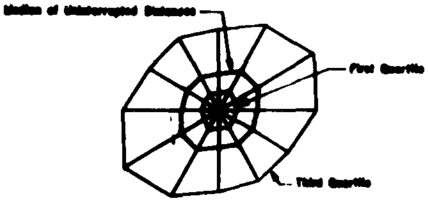

OFFICE OF NAVAL RESEARCH
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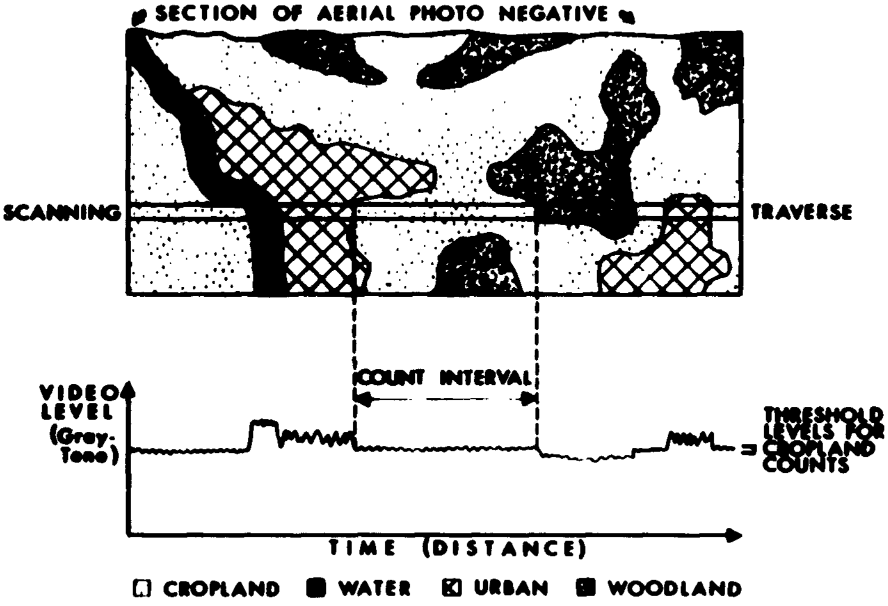
NOX

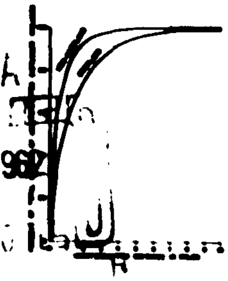
METHODOLOGY FOR INSTRUMENTED GEOGRAPHIC ANALYSIS



by James P. Latham
Principal Investigator

Technical Report No. 2, NR 387-023

BOWLING GREEN STATE UNIVERSITY
BOWLING GREEN, OHIO, MARCH 1962



Technical Report No. 2 NR 387-023

METHODOLOGY FOR INSTRUMENTED GEOGRAPHIC ANALYSIS

by

James P. Latham

Principal Investigator

Contract Nonr 3004(01)
Office of Naval Research
Geography Branch

March 1962

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Contents

ABSTRACT

The complex geographic patterns of phenomena now recorded or transmitted by aerial photography, infra-red scanners, or other image or environmental sensors provide distribution data which require rapid and rigorous methods of quantitative analysis. A "Rotated Parallel Traverses" method measures aspects of the distributants' size, shape, orientation, extension, fragmentation, and dispersion. It provides data for estimating the area of simple or complexly-shaped units or regions, and for estimating proportion of total area occuppied by each phenomena present.

The method adapts to TV-like flying-spot scanning systems which can identify phenomena, measure aspects of distribution, and output data on display panels or in tape or punch card forms suitable for computer manipulation. Measurement may be based on many sensor units of one micron size, and varied in refinement by varying the scale of the image being analyzed.

Statistical and graphically expressed descriptions of distribution can be mapped, sometimes automatically. Patterns produced by the same phenomenon in different regions, or by different phenomena in the same regions, can be quantitatively compared and described by curves or symbols, such as the "orientation rose." The isolated and quantified data of distribution permits scientific evaluation of spacial and causal relationships. Probable journey experience over areas may be statistically or graphically expressed for planning or descriptive purposes.

INTRODUCTION

Observers of television have little realization that the electronic principles being demonstrated actually are a significant possibility for the furtherance of geographic science. The flying spot of the cathode-ray tube being watched is flashing along the six hundred parallel lines of the screen with great speed, and by fluctuations in its brightness it presents an intelligible image to the viewer. The original camera that scanned the pattern of persons, objects, and scenery in view has intensely sampled with parallel traverse lines a distribution of reflected light. It has classified reality in terms of black, white, and gray tones (intensity of reflected light), and related dimensions of each unit of occurrence with a time factor determined by the distance that the unit occupied along the scan lines. Hence, here is a device that samples a complex pattern by means of intercept lengths. Characteristics of size, shape and orientation of the phenomena are directly measured by the intercepts of the flying spot scanner, classified according to type (gray tone interpreted by reflected light values) and displayed almost instantaneously in the form of an image.

Many fields of science are aware that the actual patterns which geographic phenomena display upon the surface of the earth - or otherwise distribute - are now available in overwhelming quantity, and urgently require methodology for detailed and rigorous analysis. Aerial photographs reveal the great variety of ways in which surface-located features actually occur. Remote sensing devices utilizing infra-red television or other means transmit cloud patterns and other distributions of environmental elements to laboratories for recording and study. Sizes, shapes, and orientations are recorded by controlled techniques that make accurate measurements feasible. Distance and position relationships are realistically shown and available for measurement. Interpretation of such data has produced maps of generalized but honestly complex patterns of land use or other categories.

The rapidity with which patterns of distribution are being made available for analysis is leaving scientists so overwhelmed that inadequate effort is being made to develop the methodology that can meet the challenge. Preston James has pointed out that, "In whatever part of the field a geographer specializes he finds common ground with other geographers in two ways: 1) he accepts the fundamental concept that differing patterns and associations of phenomena on the earth produce similarities and contrasts between places, and that these similarities and contrasts are significant in terms of continuing processes of change and therefore worth studying: and 2) in order to understand the significance of area differentiation more fully he defines categories of patterns and associations and studies them in their area relationships.[1] As the study of distribution lies at the heart of geography, its practitioners must seize the opportunity that is now presented. Generalizations have been highly useful despite the limited information upon which they were based. Descriptions of distribution that are evolved from rigorous measurement of pattern characteristics will be even more satisfactory for many purposes. And by meaningfully quantifying the patterns, it will be possible to provide not only scientifically improved descriptions but also precisely stated ones that will also have meaning and usefullness for engineers, agriculturists, economic planners, and others.

The Problem of Complex Distribution

The detailed recording of complex distributions is not the end but the beginning of geographic purpose. Wisdom will flow not simply from the observing of pattern but from the analysis of it. An observer may become aware of similarities, difference, and even seeming identities in the manner in which a particular phenomenon is distributed within various areas; or in the manner in which different phenomena create the same or differnt patterns. However, he often will not perceive the same relationships that other may observe, and very often he will not be consistent in his own evaluations. Furthermore, even the sharpest of observations may still be difficult to communicate effectively to others. The subjective observation of a pattern can only be described in subjective terms which often have different meanings to individuals.

Figure 1 illustrates this problem. All cropland areas in Pennsylvania over one-quarter mile in minimum size are shown here.[2] Subjective observation of this distribution notes definite patterns - such as the "clogged-up" screen pattern of the northwestern corner, the fern-like shapes of the northeast, the "fiorded coast" of cropland surrounding the urban sprawl of Philadelphia in the southeast, the "lakes on land" aspect of cropland - or of the interruptions to it - in several parts of the state. Various degrees of similarity and dissimilarity with these patterns will be noted in other areas of the state.

It is obvious that the total variety of patterns cannot be accurately described by such subjective and vague similes. There is a need for objective methods which measure the characteristics of complex distribution, and present the derived data in ways which describe the distribution. Such a method must be applicable to all the variations of the pattern so that comparability of the data is maintained. It cannot be developed by specifying "typical" size, shape, or orientation examples for various patterns because a close scrutiny indicates that some distribution may be so complexly extended that there are no clearly established units of occurrence. (The west-central part of Pennsylvania as displayed in Figure 1, and several other areas, clearly demonstrate this complication.) The method should be primarly objective in nature, and hence a valid application of the method by

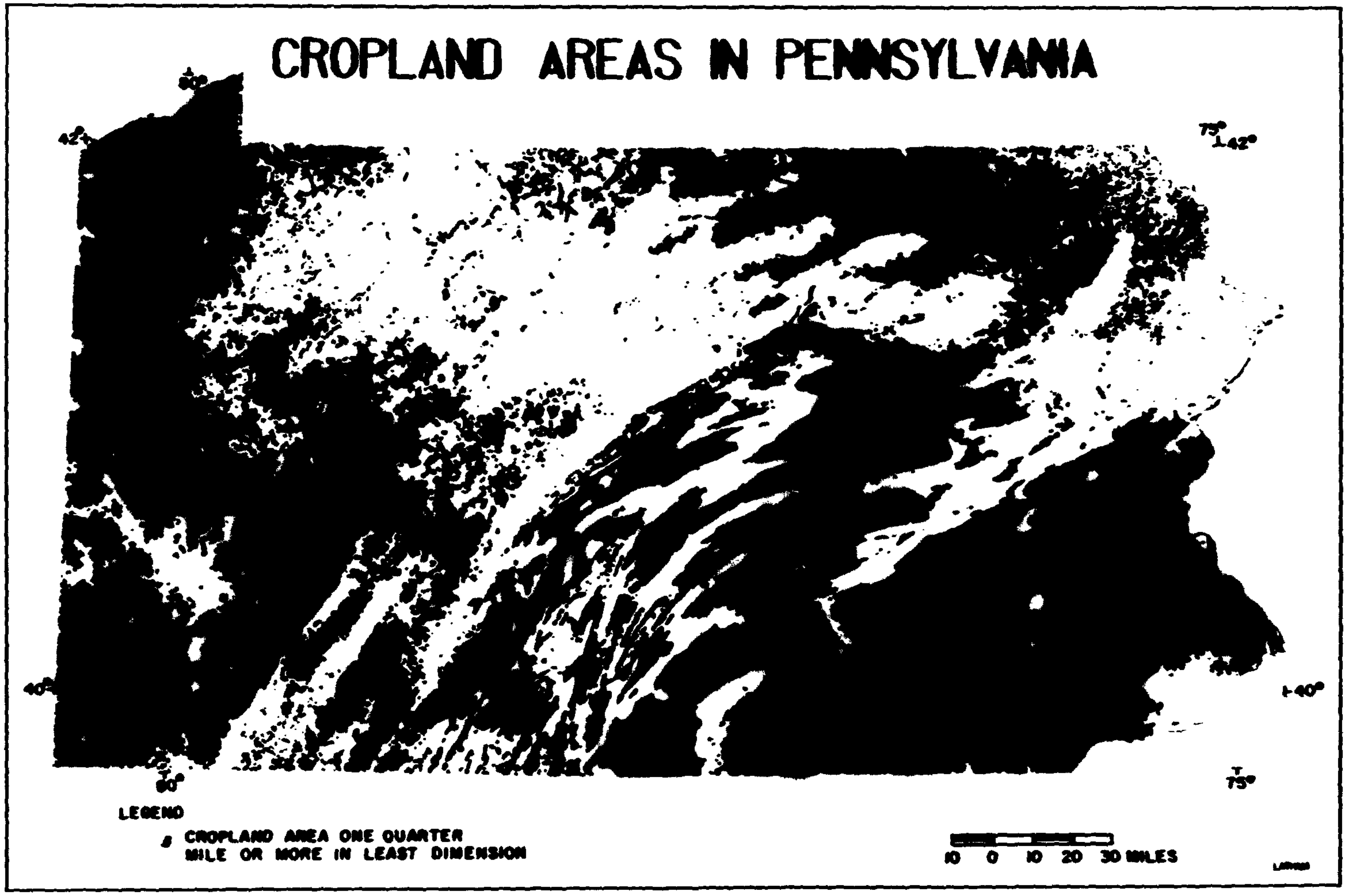


Fig. 1 Distribution of Pennsylvania cropland areas one-quarter mile or more in minimum dimension, as determined from interpretation of 1:20, 000 aerial photographs.

different investigators should yield the same result. And it is desirable for the method to lend itself to electronic instrumentation in order that it might be economically and quickly applied to geographical problems of social, political, or military importance. This article demonstrates one such methodology, and surveys electronic instrumentation for the collection and evaluation of the needed data.

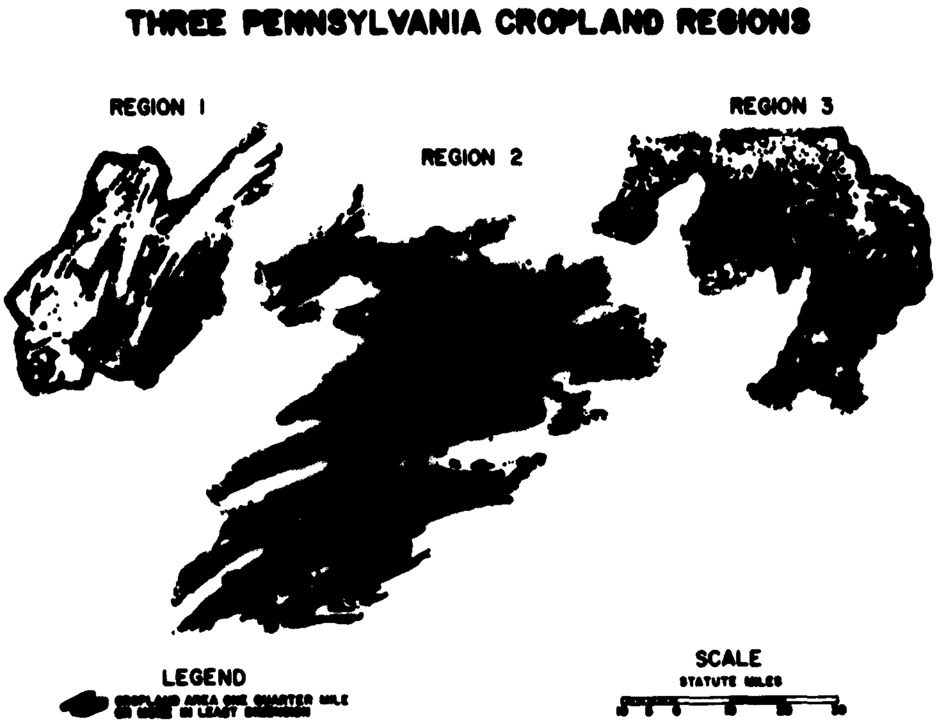


Fig. 2 Three Pennsylvania cropland regions located as follows: (1) south-central ridge and valley area; (2) middle Susquehanna River Valley lowlands in eastern part of state; (3) northeastern glaciated hill and valley area.

The Rotated Parallel Traverses Method

The three regions displayed in Figure 2 show some of the variations and complexity that may be found in geographic patterns.[3] They will now be used to demonstrate the feasibility of quantitatively analyzing complex patterns. Figure 1 is located in the Ridge and Valley Province of southcentral Pennsylvania. Region 2 is the "Middle Susquehanna Valley" area, and Region 3 is the fern-like distribution of cropland found in the glaciated hill and valley terrain of northeastern Pennsylvania. Note the difficulty of delimiting the "areal unit" of cropland or noncropland surface when the dispersant is extended in fern-like or other complex patterns.

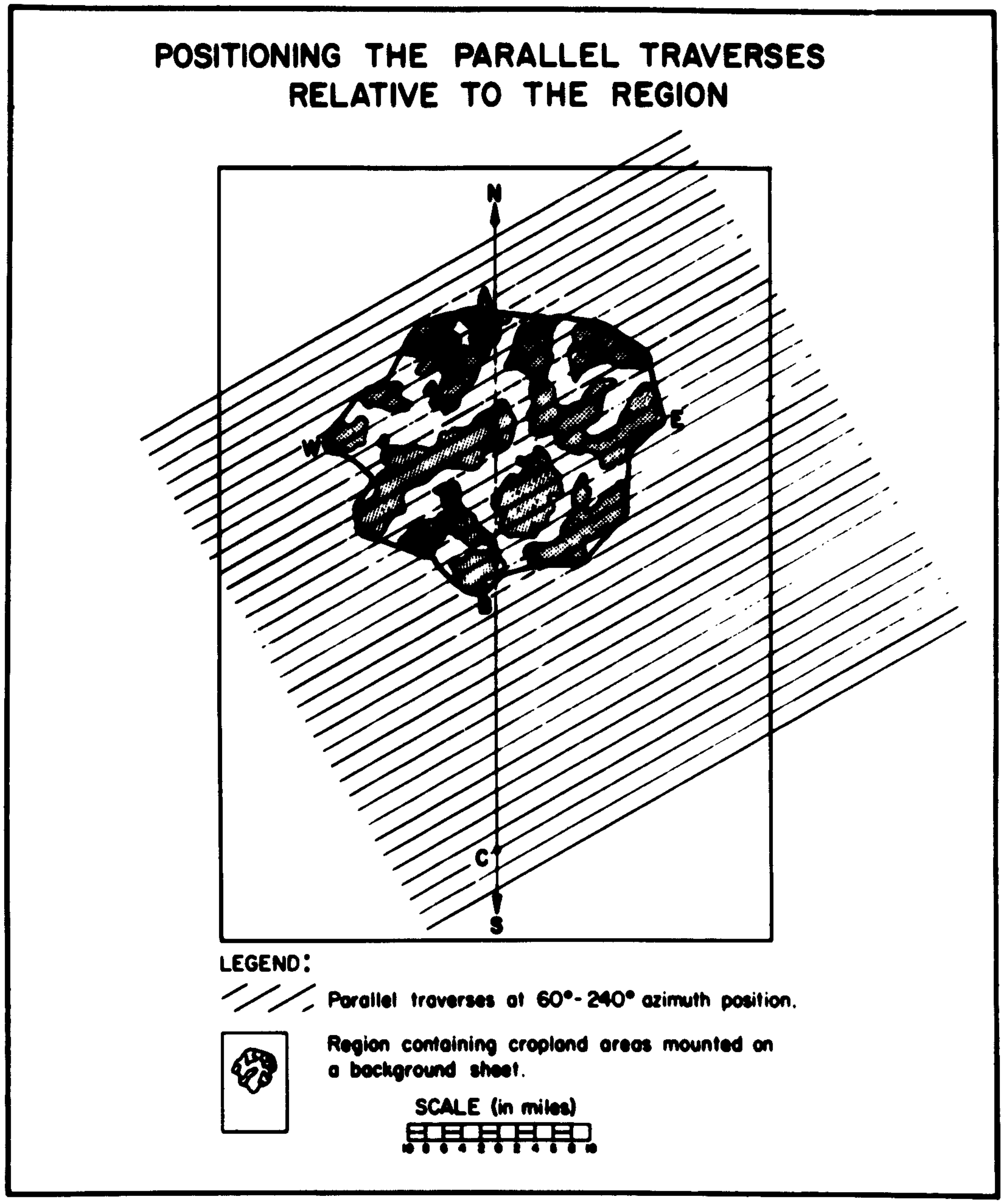


Fig. 3

Figure 3 reminds one that the sum of intercepts along a traverse has been used to estimate the proportion of total area occupied by particular surface types within a region.[4] However, investigators have not examined the use of the variations in intercept lengths as descriptive indicators of the pattern of distribution itself. Individual intercepts measure <u>uninterrupted</u> <u>distances</u> across a phenomenon surface, and their lengths result directly from the size and shape of the occurences. Intercept lengths also are directly expressive of the degree of fragmentation or interruption that is present in the region. Intercepts are significant indicators of pattern and adequate sampling of them can provide an understanding of some fundamental characteristics of the distribution. From measurement of the intercepts, it is possible to develop a quantitative description of the manner in which an areal dispersant occurs within a region. Data can be accumulated to compare various surfaces within a region, reveal directtional or orientation aspects of surface phenomena, and express interregional variations. It can also be used to estimate the total area in a complexly extended region.

A "Rotated Parallel Traverses Method" has been applied manually as follows:

The maps of each of the forty-seven Pennsylvania Cropland Regions were sampled by parallel traverses drawn to be the map scale equivalent of two miles apart. In subsequent stages of data accumulation the parallel traverses were rotated to six positions thirty degrees apart. The north-south oriented traverses were designated as the 0-180 degrees azimuth, since each traverse line samples two possible directions of movement. Other azimuths were similarly given dual identification. Figure 3 shows the traverses at the 60-240 degrees angle. The actual positioning of the sampling traverses relative to the mapped distribution was determined by a control point located on the central north-south axis of the region but as far south of the region's border as the area's contact with this axis determined. (Hence, A-B equals B-C.) As one of the parallel traverses was passed through this control point at a proper angle for the azimuth being tested - that is either at 0, 30, 60, 90, 120, or 150 degrees - it also determined the paths of the other parallel traverses sampling the region.[5] Consequently, the actual paths sampled were not chosen subjectively by the investigator.

Distances over cropland, and over non-cropland, were then measured as intercept lengths. (In the map, and hence in this discussion, the "non-cropland" includes all surface not classified as cropland.) As illustrated by Table 1, these uninterrupted distances (intercepts) over a surface type were organized in a frequency table with distance classes equivalent to onequarter mile. For each of the six azimuths tested, it shows data for both cropland and non-cropland distances. It also presents regional totals for all crossings over cropland which fall into a particular distance class, regardless of the azimuths which did the sampling. Non-cropland all-azimuths regional totals are similarly displayed. An accumulative percent is computed for cropland and non-cropland columns of each azimuth, and for all-azimuth regional totals, since this indicated what percent of the total number of category crossings are no longer than the upper limit of a class. This facilities inter-surface and inter-azmuthal comparisons.

TABLE 1 - REGION 3 - PENNSYLVANIA

NUMBER AND ACCUMULATIVE PERCENT OF UNINTERRUPTED DISTANCES ON CROPLAND AND NON-CROPLAND SURFACES SAMPLED
WITH ROTATING PARALLEL TRAVERSES - FOR EACH AZIMUTH SAMPLED AND FOR THESE AZIMUTHS COMBINED

Distance Class in Miles (Mid-Value)	0° - 180° Azimuth				30° - 210° Azimuth				60° - 240° Azimuth				90° - 270° Azimuth				120° - 300° Azimuth				150° - 330° Azimuth				Region Totals - For All Azimuths			
	Number of Occurrences		Accumulative Percent of Total		Number of Occurrences		Accumulative Percent of Total		Number of Occurrences		Accumulative Percent of Total		Number of Occurrences		Accumulative Percent of Total		Number of Occurrences		Accumulative Percent of Total		Number of Occurrences		Accumulative Percent of Total		Number of Occurrences		Accumulative Percent of Total	
	Crop-land	Non-Crop-land	Crop-land	Non-Crop-land	Crop-land	Non-Crop-land	Crop-land	Non-Crop-land	Crop-land	Non-Crop-land	Crop-land	Non-Crop-land	Crop-land	Non-Crop-land	Crop-land	Non-Crop-land	Crop-land	Non-Crop-land	Crop-land	Non-Crop-land	Crop-land	Non-Crop-land	Crop-land	Non-Crop-land	Crop-land	Non-Crop-land	Crop-land	Non-Crop-land
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)
0.25	126	80	34.81	20.67	182	143	43.86	32.72	149	102	39.00	25.12	197	125	48.28	28.93	161	111	39.75	25.99	192	154	44.55	33.92	1007	715	41.91	28.12
0.50	100	93	62.43	44.70	122	95	73.25	54.46	115	104	69.10	50.73	107	87	74.50	49.07	129	93	71.60	47.77	126	92	73.78	54.18	699	564	71.00	50.30
0.75	57	62	78.18	60.72	50	42	85.30	64.07	41	47	79.83	62.31	55	51	87.98	60.88	60	70	86.41	64.16	54	54	86.31	66.07	317	326	84.19	63.12
1.00	35	38	87.85	70.54	29	38	92.29	72.76	39	46	90.04	73.64	21	49	93.13	72.22	34	53	94.80	76.57	22	40	91.41	74.88	180	264	91.68	73.50
1.25	11	22	90.89	76.22	13	23	95.42	78.02	18	25	94.75	79.80	16	27	97.05	78.47	7	24	96.53	82.19	17	28	95.35	81.05	82	149	95.09	79.36
1.50	14	20	94.76	81.39	7	15	97.11	81.45	6	16	96.32	83.74	5	23	98.28	83.79	9	14	98.75	85.47	10	9	97.67	83.03	51	97	97.21	83.17
1.75	7	10	96.69	83.97	5	12	98.31	84.20	4	18	97.37	88.17	5	19	99.51	88.19	3	11	99.49	88.05	6	22	99.06	87.88	30	92	98.46	86.79
2.00	7	14	98.62	87.59	2	14	98.79	87.40	3	16	98.16	92.11	1	7	99.75	89.81	1	11	99.74	90.63	1	9	99.29	89.86	15	71	99.08	89.58
2.25	2	9	99.17	89.91	1	15	99.03	90.83	2	1	98.68	92.36	1	12	99.99	92.59	1	6	99.99	92.04	1	10	99.52	92.06	8	53	99.41	91.66
2.50		10		92.49	2	5	99.51	91.97	5	10	99.99	94.82		8		94.44		6		93.45		10		94.26	7	49	99.70	93.59
2.75		2		93.01	1	6	99.75	93.34		8		96.79		5		95.60		3		94.15	2	7	99.98	95.80	3	31	99.82	94.81
3.00	1	5	99.45	94.30	1	7	99.99	94.94		3		97.53		3		96.29		6		95.55		4		96.68	2	28	99.90	95.91
3.25	2	3	100.00	95.07		5		96.08						2		96.75		6		96.95		2		97.12	2	18	99.98	96.62
3.50		5		96.36		2		96.54		4		98.51		3		97.44		2		97.42		3		97.78		19		97.37
3.75		3		97.13		3		97.23		1		98.76		1		97.67		2		97.89		1		98.00		11		97.80
4.00		3		97.90		2		97.69		1		99.01		2		98.13		2		98.36		3		98.66		13		98.31
4.25		1		98.16		3		98.38						1		98.36		1		98.59						6		98.55
4.50						2		98.84		2		99.50		2		98.82										6		98.79
4.75		1		98.42		1		99.07						1		99.05		2		99.06						5		98.99
5.00		1		98.68		1		99.30						1		99.28						1		98.88		4		99.15
5.25		1		98.94										1		99.51		2		99.53		2		99.32		6		99.39
5.50		1		99.20																						1		99.43
5.75																												
6.00		1		99.46		1		99.53										1		99.76						3		99.55
6.25																												
6.50		1		99.72						2		99.99														3		99.67
6.75																												
7.00																												
7.25																		1		99.99		1		99.54		2		99.75
7.50																												
7.75														1		99.74										1		99.79
8.00																												
8.25														1		99.97										1		99.83
8.50						1		99.76																		1		99.87
8.75																												
9.00																												
9.25																						1		99.76		1		99.91
9.50																												
9.75																												
10.00																												
10.25																												
10.50						1		99.99																		1		99.95
10.75																						1		99.98		1		99.99
11.00		1		99.98																						1		100.03
Totals	362	387	100.00	99.98	415	437	99.99	99.99	382	406	99.99	99.99	408	432	99.99	99.97	405	427	99.99	99.99	431	454	99.98	99.98	2403	2543	99.98	100.03

Source: Original measurements from 1:500,000 map of "Cropland Areas in Pennsylvania" (Figure 1).

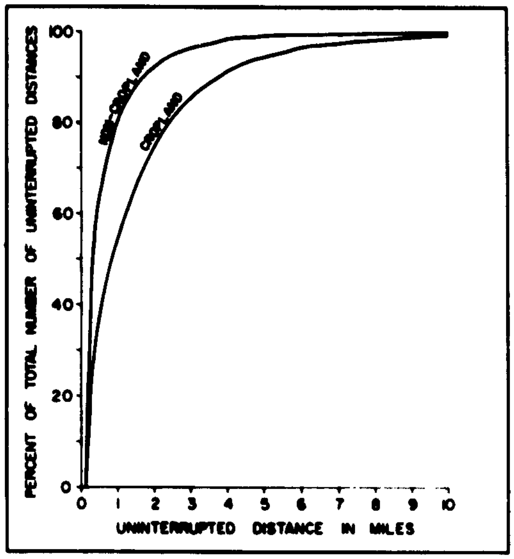


Fig. 4 Inter-surface comparison of distances over cropland and non-cropland in Pennsylvania Region 2, as indicated by totaled sampling along six azimuths.

Figures 4, 5, 6, and 7 demonstrate how such information may be used to graphically analyze and describe characteristics of distribution patterns. Figure 4 compares cropland and non-cropland characteristics of Region 2. It indicates that for generalized movement within this region distances over cropland are predominently greater than those over non-cropland. From the chart, the percent of cropland or non-cropland crossings that will or will not exceed a certain distance can be estimated. For example, it is seen that although a passage of one mile or less crosses 80 percent of the non-cropland surfaces, only 55 percent of the passages over cropland were so limited. It is observed that less than 2 percent of the non-cropland distances exceed 4 miles. It is true, of course, that more detailed and exacting quantitative comparisons can be made directly from the columns of the table, but the graph presents the facts of the distribution in a simplified and vivid manner which more effectively communicates the variations resulting from the pattern of distribution.

Figure 5 displays the accumulated percentage distributions for the cropland distances sampled in the three regions. These are all-azimuths-combined percentages. It is apparent that distances on cropland are usually short in Region 3 (the northeastern glaciated area), longer in Region 1 (the ridge and valley area), and relatively quite long in Region 2 (the "Middle Susquehanna Valley" area). Although over 90 percent of the passages on cropland in Region 3 and 86 percent of the cropland passages in Region 1 are one mile or less in length, only 56 percent of the cropland

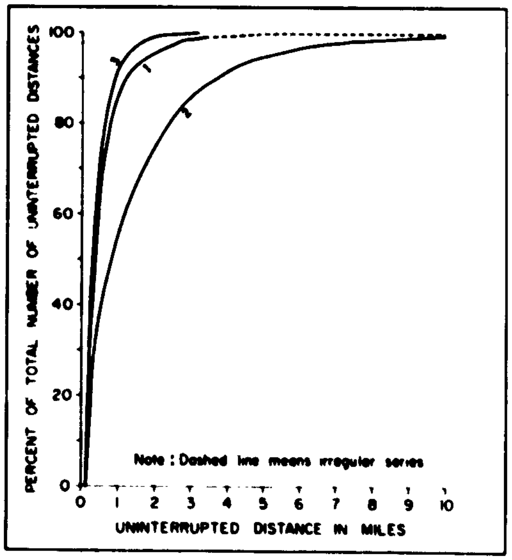


Fig. 5 Inter-regional comparisons of distances over cropland in three Pennsylvania regions, as indicated by totaled sampling along six azimuths.

distances in Region 2 are so limited. A distance of three and one-quarter miles includes all crossings over cropland in Region 3 and 98 percent of them in Region 1, but only 86 percent of the cropland passages in Region 2 are this short. Such inter-regional comparisons of distance over surface types sharply expresses some distribution variations that exist between regions due to the differences in the patterns. The number of regions that can effectively be compared in one such graph will vary with the scale of the presentation and the degree of similarily of the curves.

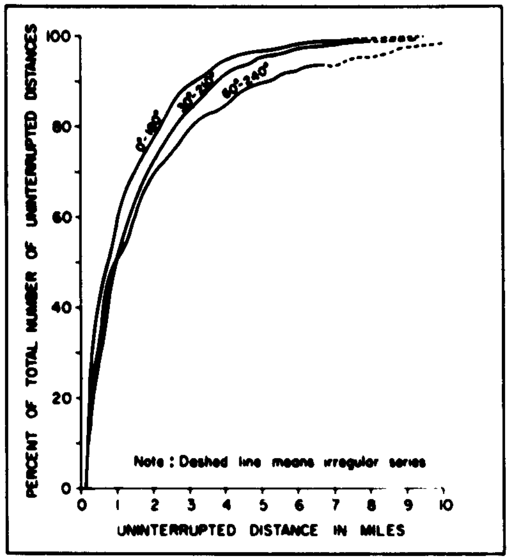


Fig. 6 Inter-azimuth comparisons of distances over cropland in Pennsylvania Region 2, for three azimuths indicated.

Distances over cropland along three of the azimuths sampled in Region 2 are represented in Figure 6. By comparing these results, orientation aspects of the pattern of distribution are clarified, since the journey over cropland will be longer as the sampling azimuth rotates into a position which follows the predominent direction of the pattern. The trend of the cropland in Region 2 toward a northeastern and eastern orientation is displayed. Along the north-south azimuth (0-180 degrees), a distance of two and one-quarter miles crosses 80 percent of the cropland traversed, but a distance of three miles is necessary to include 80 percent of the distances along the 60-240 degree azimuth which points east of northeast. It is noticeable that the relationships among the three azimuths are not similarly consistent when the curves depict the 50 percent or so of the crossings that do not exceed one mile. This is understandable, since cultural and minor physical factors not necessarily related to major environmental influences - such as the orientation of a valley - are more significant as modifiers of small units of land use.

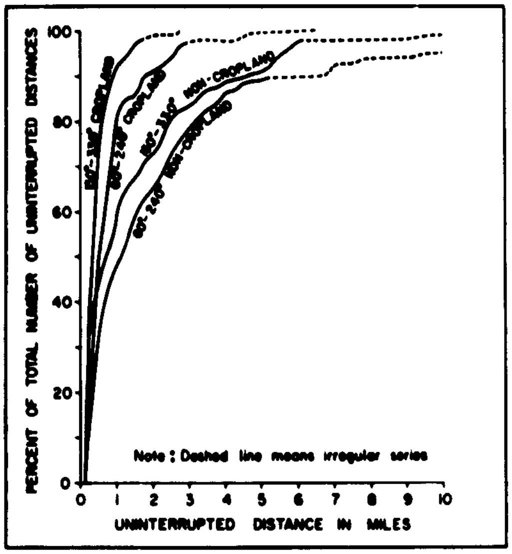


Fig. 7 **Inter-surface and inter-azimuth comparisons indicated of distances over cropland and non-cropland in Pennsylvania Region 1, which has prouounced orientation influences.**

For some purposes, significant aspects of the distribution are more readily perceived and utilized when summarized in statistical values. Table 2 indicates the median and quartile values of distances sampled on cropland and non-cropland in the three regions. The medians emphasize the distance that is not exceeded by 50 percent of the journeys across a surface type. Of course they also indicate a distance that half of the journeys did exceed. Quartiles point out the distances that are not exceeded by 25 or 75, percent of the passages over a surface type. Maximum distances recorded are also shown, since knowledge of the longest possible passage might be vital. Values are presented for each azimuth and for all-azimuths regional totals.

Figure 7 shows that both cropland and non-cropland crossings in Region 1 tend to be shortest for the 150-330 degrees azimuth, and longest along the 60-240 degrees azimuth; but it is also evident that non-cropland distances are predominently longer. It is noticeable that the direction which indicates the shortest crossings of non-cropland displays distances that predominently exceed the longer distances over cropland. Non-cropland surfaces in this region will obviously be larger. The chart also shows that if the length of the passage exceeds one mile, passages over cropland will seldom be longer than the passages over non-cropland.

Table 2. **Statistical Summary of Distances over Surface Types in 3 Pennsylvania Regions**

(in miles)

Region 1

Azimuth	First Quartile		Median		Third Quartile		Maximum	
	Crop-land	Non-crop-land	Crop-land	Non-crop-land	Crop-land	Non-crop-land	Crop-land	Non-crop-land
All Azimuths Combined	.31	.32	.31	.97	.68	2.31	14.73	20.33
0-180 deg.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60-240 deg.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
150-330 deg.	.39	.31	.44	.66	.60	1.30	2.07	13.60

Region 2

Azimuth	First Quartile		Median		Third Quartile		Maximum	
	Crop-land	Non-crop-land	Crop-land	Non-crop-land	Crop-land	Non-crop-land	Crop-land	Non-crop-land
All Azimuths Combined	.43	.27	.86	.66	1.16	.88	18.08	20.33
[illegible]	.40	.23	[illegible]	.38	[illegible]	[illegible]	[illegible]	4.75
[illegible]	.36	.30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	.41	.27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	.31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	.41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	.46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Region 3

Azimuth	First Quartile		Median		Third Quartile		Maximum	
	Crop-land	Non-crop-land	Crop-land	Non-crop-land	Crop-land	Non-crop-land	Crop-land	Non-crop-land
All Azimuths Combined	.27	.35	.44	.62	.70	1.19	3.23	11.60
[illegible]	.30	[illegible]	[illegible]	.71	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	.27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	.31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

THE ORIENTATION ROSE – FOR PENNSYLVANIA REGION 2

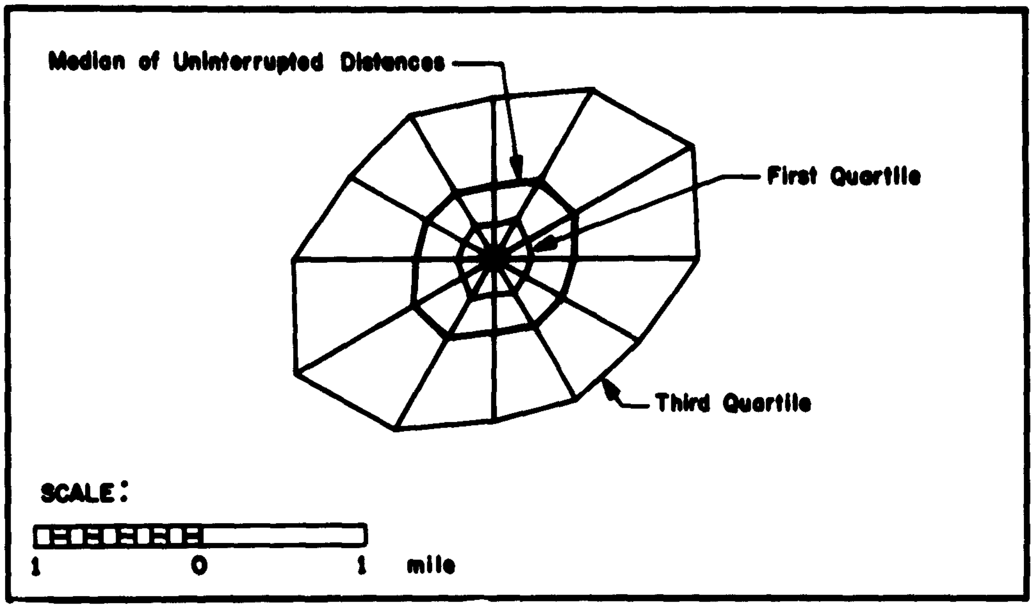
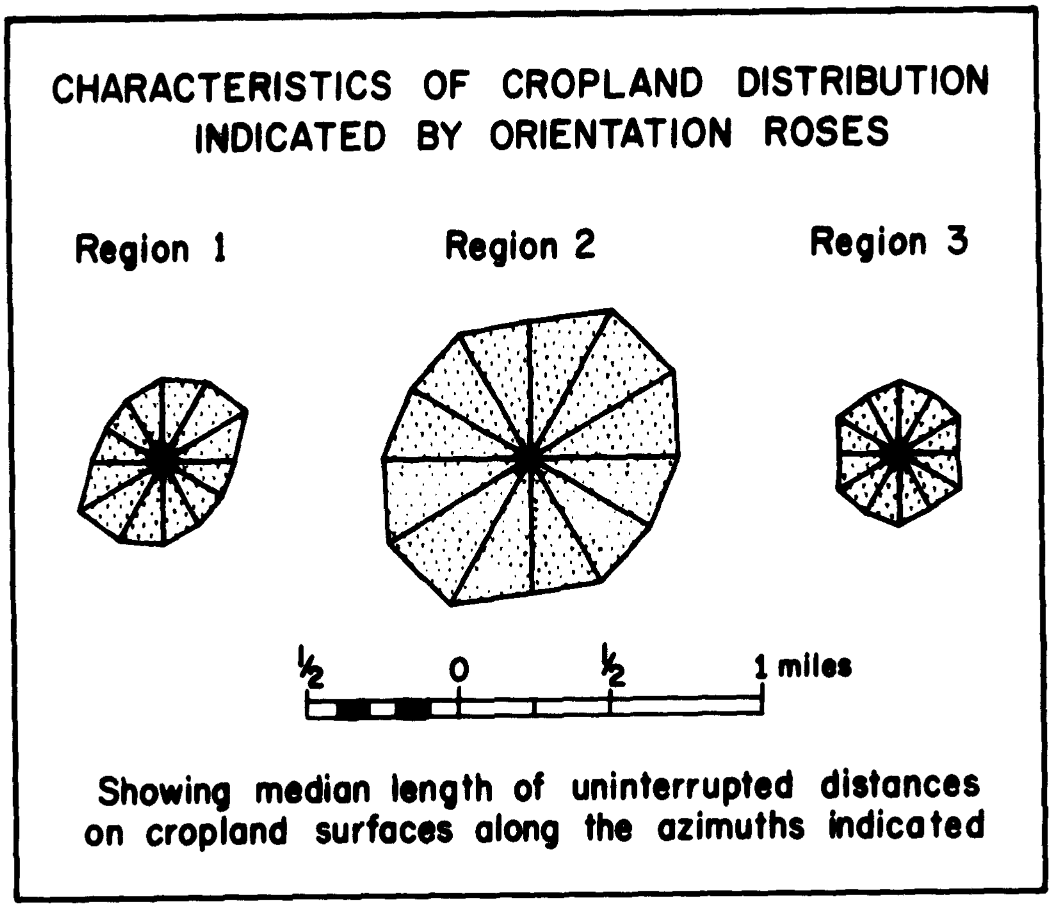


Fig. 8 Characteristics of cropland distribution in Pennsylvania Region 2, as graphically indicated by a six azimuth orientation rose.

The graphic device in Figure 8, herewith designated "the Orientation Rose", summarizes distribution characteristics in a symbol which facilitates regional comparison. By drawing a line which is a scaled representation of the median (or a quartile) of the distances over croplands sampled by a particular azimuth, and orienting the line as the azimuth is oriented, there is created a visual expression of the median (or quartile) crossing of cropland. The center of this line is crossed by median-sized (or quartile-sized) lines representative of other azimuth samplings, with each line centered at the point of intersection. The resulting symbol presents a quantitatively-based comparison of the sampled cropland distance, and also indicates the generalized orientation of cropland in the region. It is a symbolic indication of the median size and shape of corpland extension, and an indication of the abstract "typical unit" in a complex distribution not having isolatable units. When quartile distances are included, the range of passages over cropland will be suggested. The same symbolization of non-cropland can suggest the generalized dispersion of cropland.



CHARACTERISTICS OF CROPLAND DISTRIBUTION INDICATED BY ORIENTATION ROSES

Showing median length of uninterrupted distances on cropland surfaces along the azimuths indicated

Fig. 9

Summarized in Figure 9 are median characteristics of cropland extension in the three demonstration regions. The Region 2 symbol indicates the large cropland expressions common in the Susquehanna area, and the modified northeast-southwest orientation influence. The narrow, variously oriented cropland occurrences in the northeastern sector of the state provides a smaller contrasting symbol for Region 3, which indicates a rather limited north-south emphasis. The characteristic northeast-southwest trend of elongated valley cropland in south-central Pennsylvania is reflected in the symbol for Region 1.

The Rotated Parallel Traverses Method of analysis has been applied to all 47 cropland regions of Pennsylvania. Figure 10, shows the "Medians of Distances Over Cropland Indicated by Orientation Roses". A study of the mapped symbols confirms and quanitfies the great variations among cropland patterns in Pennsylvania.[6] It is evident, for instance, that the median journey over cropland in the southeastern cropland region is very large relative to that in other

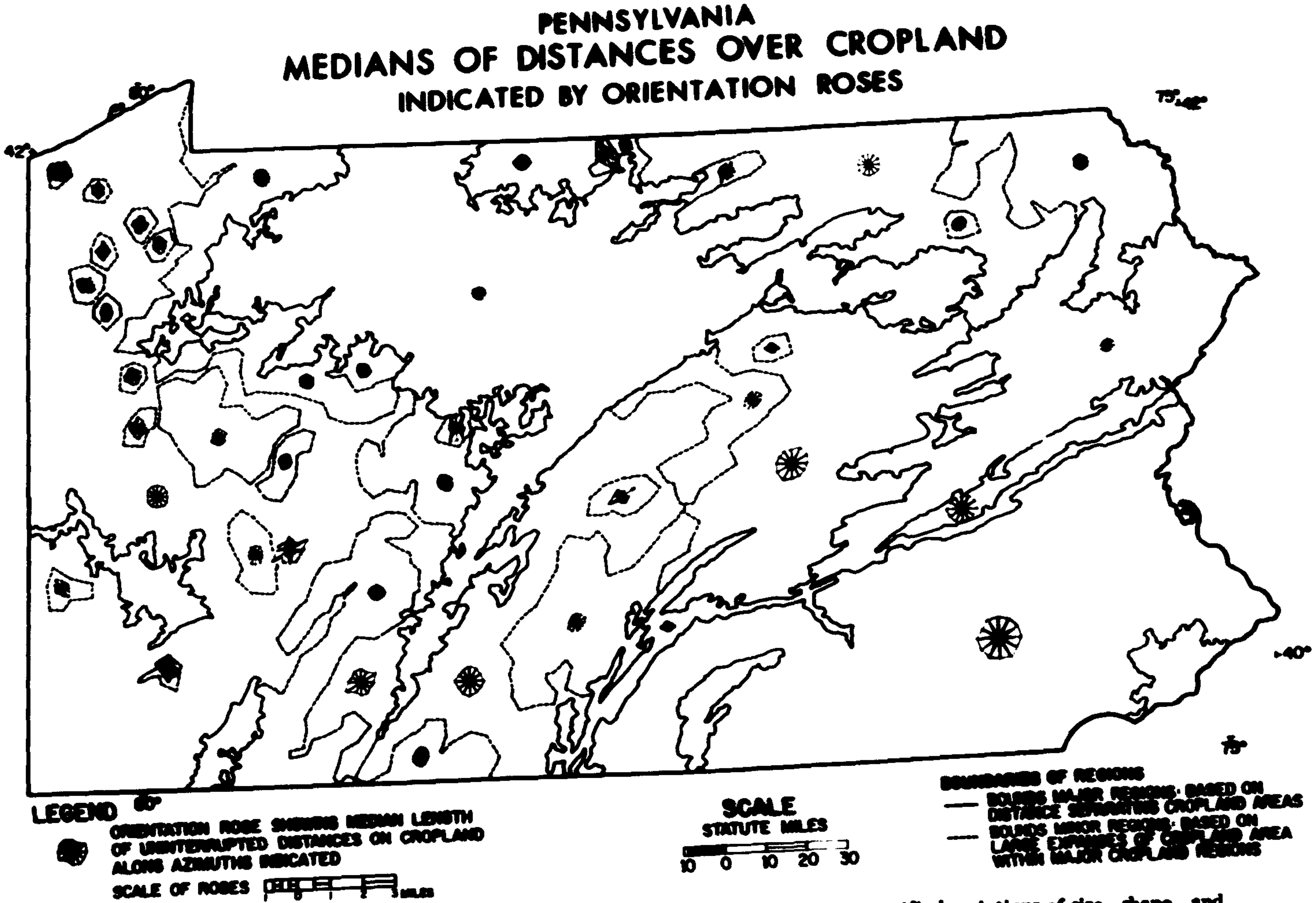


Fig. 10 Orientation roses for Pennsylvania cropland regions display quantified variations of size, shape, and surface distances that result from a complex pattern of distribution. They provide a statistical indication of experience journeying over cropland within each region.

regions. The smaller median of cropland occurrence in the "Susquehanna Lowland" (Region 2 of the examples) displays a generally northeast-southwest orientation, but this orientation is even more pronounced for the valley cropland in the central part of the state. The narrow and interrupted occurences of cropland in the northeastern corner of the state (Region 3 of our examples) results a limitation on straight line extension of cropland and the complex pattern displays little directional predominence. The medium to small sized roses for cropland in the western part of the state suggest the fact that cropland use is frequently interrupted by both terrain conditions and alternate land uses. It is observable that the elongated roses influenced by the trend of the Allegheny Front, give way to almost circular roses in the complexly dissected plateau and then approach a rectangular shape in some areas of the lake plain, where cultural plan rather than physical obstacles influenced the pattern.

In interpreting the roses, it must be remembered that they indicate the medians of distances over cropland sampled and do not indicate how much cropland exists within the region. For example, the orientation rose for the large north-central region which is predominently non-cropland is almost as large as the symbol for the northeastern region, but the proportions of their surfaces in cropland is 1.9 and 34.9 percent respectively.

Estimating Proportional Surface Occupancy

As indicated earlier, Joseph Trefethen successfully adapted the Rosiwal method of petrographic analysis to the sampling of areas either in the field or as represented on a map. He pointed out that: "it is assumed that the percentage of the total length of the traverses, the indricatrix, made by any type recorded on the traverse represents the areal percentage of that type for the whole area outlined."[7] Malcolm J. Proudfoot investigated the adequacy of sampling data so collected. The percentages of the total traverse length that were associated with particular land types, as indicated by the sum of their intercepts with the traverse, were compared with the percentages obtained by planimeter measurements of the same land types. The deviation was found to be less than one percent in all cases tested.[8] Hence, it is well established that the percent of a total area occupied by a dispersant (e.g., cropland) can be estimated adequately by totaling the lengths of the dispersant's intercepts with the traverses and dividing this sum by the total length of the sampling traverses. Both the aforementioned investigators declare sampling is adequate when the total traverse length is one hundred times the average intercept of the phenomenon being sampled, but Proudfoot adds one qualification: "However, for a type comprising less than 5 percent, this ratio apparently must be increased beyond 100 to 1".[9]

The intensity of sampling that has been applied by the Rotated Parallel Traverses Method to the regions under discussion usually results in a traverse length that is many hundred times greater than the length of the mean intercept of the phenomenon, cropland or non-cropland. Hence, the estimation of proportional surface occupancy by the utilization of data already gathered is feasible.

The establishment of an accurate mean cropland intercept is not a simple process, however, as the thousands of intercepts have been measured in terms of quarter-mile units, and recorded in a frequency class table. It is obvious that all the intercepts are not exactly of the length represented by the midpoint of the distance class in which they are grouped, but rather are of lengths which may vary up to one-eighth of a mile from this value. This is fundamentally a problem of refinement in measurement. If the intercepts had been measured in terms of one-thousandth of an inch, they would really be in terms of distances classes one-thousandth of an inch long. Although their exact lengths are not available, the accepted alternative in statistical procedures is to assume that "the mean of the observations in each class has the same value as the midpoint of the class. This assumption will ordinarily not be true, of course, but fortunately the errors tend to cancel."[10] Multiplying the cropland (or non-cropland) frequencies by the midpoint of their distance class, and totaling the products secured for each of the classes, gives the total length of traverse associated with the intercepts of cropland. Then division by the total number of cropland intercepts yields the intercept mean for verifying sampling adequacy.

As the total length of the sampling traverses is the total of the cropland and non-cropland intercepts, it is of course quite simple - after the above procedure has also been applied to the non-cropland intercepts - to determine the total traverse length and also to determine what percent of it is associated with either phenomenon surface, and hence what proportion of the total area is occuppied by a phenomenon.

The application of this method estimated the percent of surface occuppied by cropland in the Pennsylvania regions. For the three demonstration regions, it is:

Region 1 - 25.25 percent cropland
Region 2 - 67.27 " "
Region 3 - 34.98 " "

Area Estimates from the Data

As the parallel traverses applied to the region are the equivalent of two miles apart, each traverse can be conceived as passing through the center of a two mile wide corridor of linearly distributed area, and consequently each mile equivalent of traverse line is a count of two square miles of area. Assuming this to be true, then multiplying by two the totaled length of all intercepts with both cropland and non-cropland - or the independently recorded total traverse length - will give the square mile area of the region being sampled. However, this would only be true for the special conditions illustrated as follows:

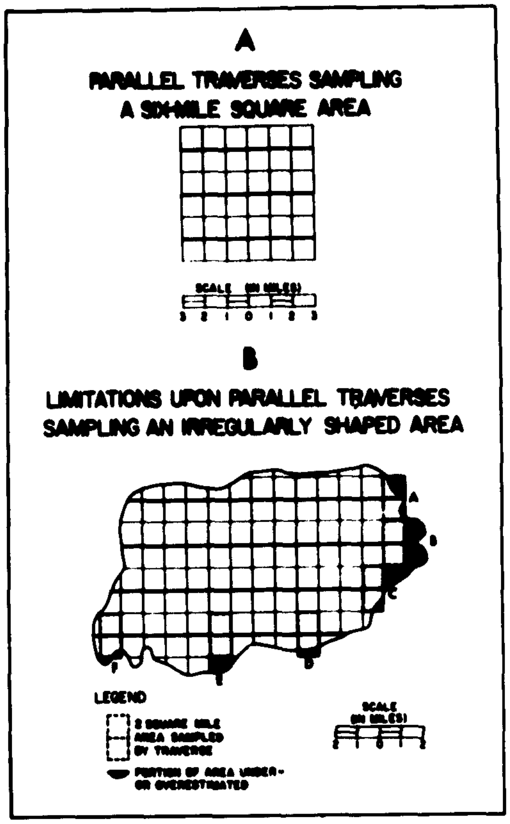


Fig. 11

If an area being sampled is 6 miles square, and the first and last traverse lines crossing the region are parallel to and 1 mile from the borders of the region, as shown in Figure 1: A, this area would be sampled by three traverse lines, each 6 miles long, and by a total traverse length of 18 miles. As each mile of the traverse would have a square mile of area on each side of it, then 2 times 18 will yield 36 square miles: the proper area for a six-mile square.

When this principle is applied to irregularly shaped areas, as shown in Figure 11B, some limitations immediately are apparent. The observed limitations upon the sampling are:

a. The irregular nature of the border may cause the traverse lines approaching it to have something less than one square mile of area on each side of a traverse mile, as shown near A; consequently traverse sampling will overestimate the area.

b. If the area extends beyond the point where the traverse line contacts the border, on either side of this point, as shown near B, there will be no traverse mile to sample this portion of the area; consequently traverse sampling will underestimate the area.

c. Combinations of the above two circumstances may occur, as near C.

d. When the traverse line nearest to the border is approximately paralleling the border of the area, the border of the area may be less than one mile from the traverse as near D; consequently traverse sampling will overestimate the area.

e. When the traverse line nearest to the border is approximately paralleling the border of the area, the border may be more than one mile but less than two miles from the traverse, as near E; consequently traverse sampling will underestimate the area.

f. Combinations of the above two circumstances may occur, as at F.

These are all valid limitations and are very likely to be present when area is sampled by parallel traverses in the manner illustrated. However, there is a probability that when irregularly shaped regions are sampled by parallel traverses which are closely and systematically spaced, and when these lines are rotated so that at least six different azimuthal directions are sampled, the variations of the above limitations will be so numerous that the overestimates and underestimates will tend to cancel out. This being so, a close estimate of the area of the region can be accomplished by utilizing the data already available from this study.

As each of the 47 Pennsylvania Regions were measured in a particular azimuthal direction, the total length of traverses sampling each region was recorded. In order to "average out" the influence of the six traverse directions relative to the directions of the region's borders (which the traverses either parallel, approach perpendicularly, or are related to in a variation between these two extremes) the total traverse lengths for all of the six azimuths were added and the resulting total traverse length for six directions was then divided by six. The quotient resulting is the total traverse length for an "average" direction, and thereby the biased relationship between particular azimuths and the direction of the border has been reduced as an influence on the area measurement. When this "average" traverse length is multiplied by two, the product is the estimate of the region's area.[11]

For the relatively complex shapes of the three regions being demonstrated in this article, the results were:

Region 1 - 1,050.92 square miles
Region 2 - 3,130.75 " "
Region 3 - 1,394.75 " "

When the area estimates for the forty-seven complexly-shaped regions in Pennsylvania were totaled, they estimated a total area for the state to be 44,954.07 square miles. The U. S. Census Bureau estimates the area of the state to be 45,333.0 square miles, and includes some bordering water areas not in the land use map. This is a difference of .90 of 1.0 percent, or better, and within the range of the normal polar planimeter error. It seems probable that this method may be very satisfactory for most purposes requiring area estimates of simple or complexly extended shapes.

When detailed intercept data on phenomena within a region is not needed, estimating the area of complexly shaped units can be rather quickly accomplished by applying a template of parallel traverses and utilizing an adding machine to total the lengths of traverse in contact with the unit's surface. After the traverses have been systematically rotated through several azimuth positions - the more positions, the greater the accuracy - a total can be struck and then divided by the number of rotation positions. When the quotient is multiplied by two - if the traverses were the equivalent of two miles apart - the estimate of area is secured. Of course the distance between traverses, and the units of measurement along the traverse length, [illegible] varied as desired just so long as proper adjustments are made.

In summary, it has been demonstrated that the Rotated Parallel Traverses Method of analyzing complex distributions can accumulate data which may be used to:

a. Describe quantitatively some characteristics of patterns.

b. Statistically summarize or describe patterns.

c. Graphically display differences or similarities in size, shape, extension, orientation, dispersion, and distance relations of the distributants within an area.

d. Estimate the total area of complexly extended areas.

e. Estimate the proportion of an area that is occupied by each type of areal phenomenon that it contains.

f. Compare various areas or regions in terms of the above quantitative characteristics.

g. Compare the patterns of various phenomena for quantitatively measured differences or similarities.

Although this demonstration has been limited to a two category map, the same method can be applied to a map containing a much greater variety of phenomena, and the same type of analysis performed for each of the measurable patterns. It may also be applied directly to small or large scale aerial photography if the phenomena of interest can be adequately identified and bounded. The latter requirement may or may not require some preprocessing of the photography.

Electronic Instrumentation

Sampling pattern characteristics adequately will often require the measurement of tens of thousands of intercepts. And if the intensity of the analysis is increased by narrowing the distance between parallel traverses or by increasing the number of azimuths sampled, there is a great multiplication of the intercepts needed. They must be measured precisely, sorted by distributant type and size, arrayed or tabulated in a frequency table, and statistically evaluated. For investigations of one phenomenon complexly distributed over a large area, or of several phenomena distributed within a small area, manual methods can be employed; providing, of course, that the weeks and months of man-hours required will be justified by the result, and the findings of the investigation will still be useful when the task is completed. But when the processes are carried out by directly applied human means, restrictions of visual and mechanical skill limit the accuracy of the data. The slow, tedious process of applying a finely calibrated rule to each intercept, judging its length as exactly as vision and physical positioning permits, and recording such readings reliably is a fatiguing task. Subsequent sorting and computation of the data is slow and laborous.

Mannual methods delay the securing of a significant analysis, and limit application to the non-urgent investigations which permit a considerable time lag. Labor costs limit even the study of the more stable patterns available, such as forest cover, lakes on land, or sea islands. And they discourage a refinement of the analysis which could sharpen and expand the information content. Delay particularly restricts use of the method for predictive purposes. Many dynamic patterns are now rapidly available by aerial or space photography or by electronic transmission of images and they can be secured in time sequences if desired. Rapid quantitative description and analysis of flood waters, cloud formations, cropland utilization, ice fragments on water, or other significant patterns would have many important scientific and applied uses. And if quantitative pattern signatures can be established, there is a possibility that automatic screening of photographs or electronic images can select those containing patterns of interest.

The advantages of an accurate, quick, and economically feasible system to perform the measurement, organize the data, and statistically evaluate the data has encouraged a search for instrumentation of the process. The flyingspot cathode ray tube provides the basic device needed to instrument the measuring of a complex pattern. Although the tube of a home television set is rather limited in resolution, its more sophisticated offspring can provide up to three thousand parallel scanning lines and an equal number of sensor units per line (9 million points for the area). The sensor units performing measurement would be about one micron in size. By optical devices, the tube scanning could be applied to a 9 by 9 inch field - the standard negative size of aerial photography - or to some other sized field if required. This establishes a possibility of measuring intercepts in length classes as little as one micron long. Of course, the ground distance that this micron represents would vary with the scale of the pattern presented to the scanner.

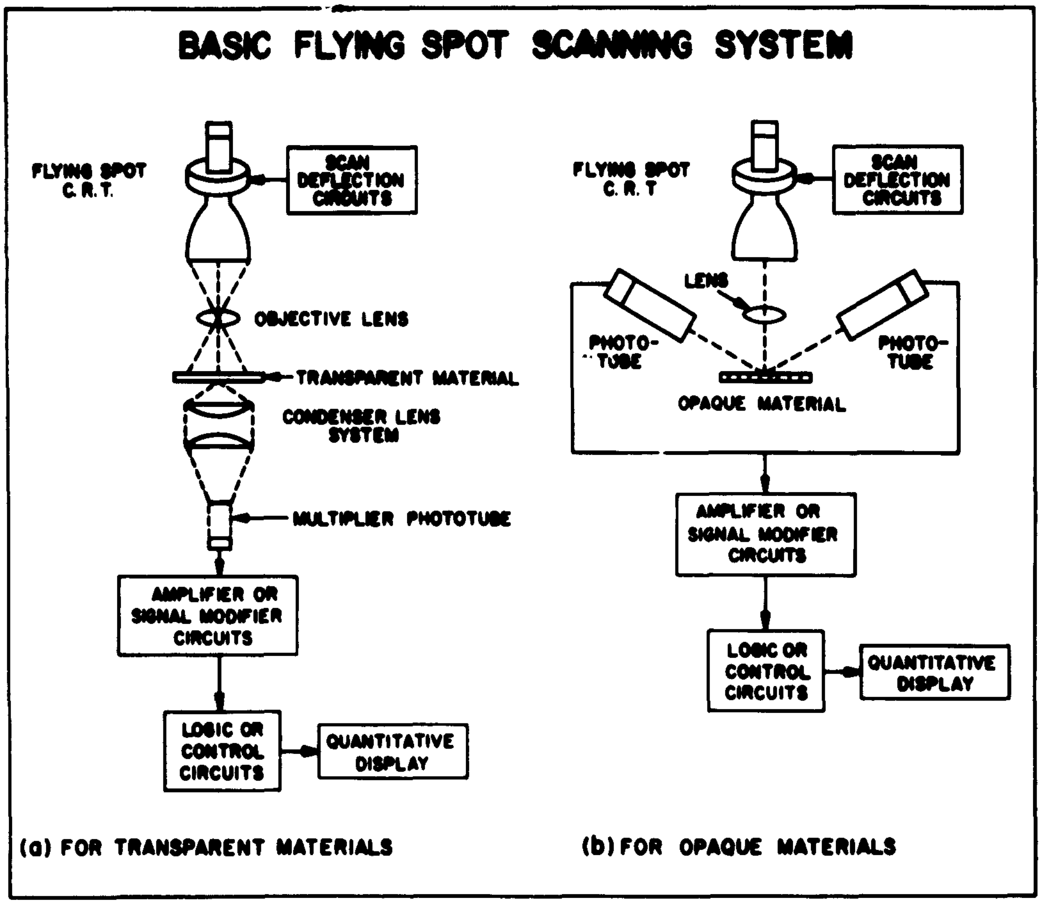


Fig. 12

Figure 12 illustrates the basic components of two flying spot scanning systems which can be adapted to the analysis of geographic patterns. Although it is possible to scan patterns printed on opaque material, such as the ordinary chart or map, the hazards of uneven light reflection and other factors decrease precision in measurement. It would be preferable, and often more convenient, to scan a pattern displayed on transparent material, such as photographic film.

Figure 13 diagrams the operations of one type of flying spot scanning system. The scanner can be applied to map patterns presented on transparent film or to negatives of photography. A simplified machine would distinguish only black or white patterns (i. e.: opaque or transparent); but more elaborate instrumentation can distinguish ranges of gray tones, and display its measurements accordingly. This segregation by thresehold levels of grayness (film density) is actually a segregation of particular surface phenomona,

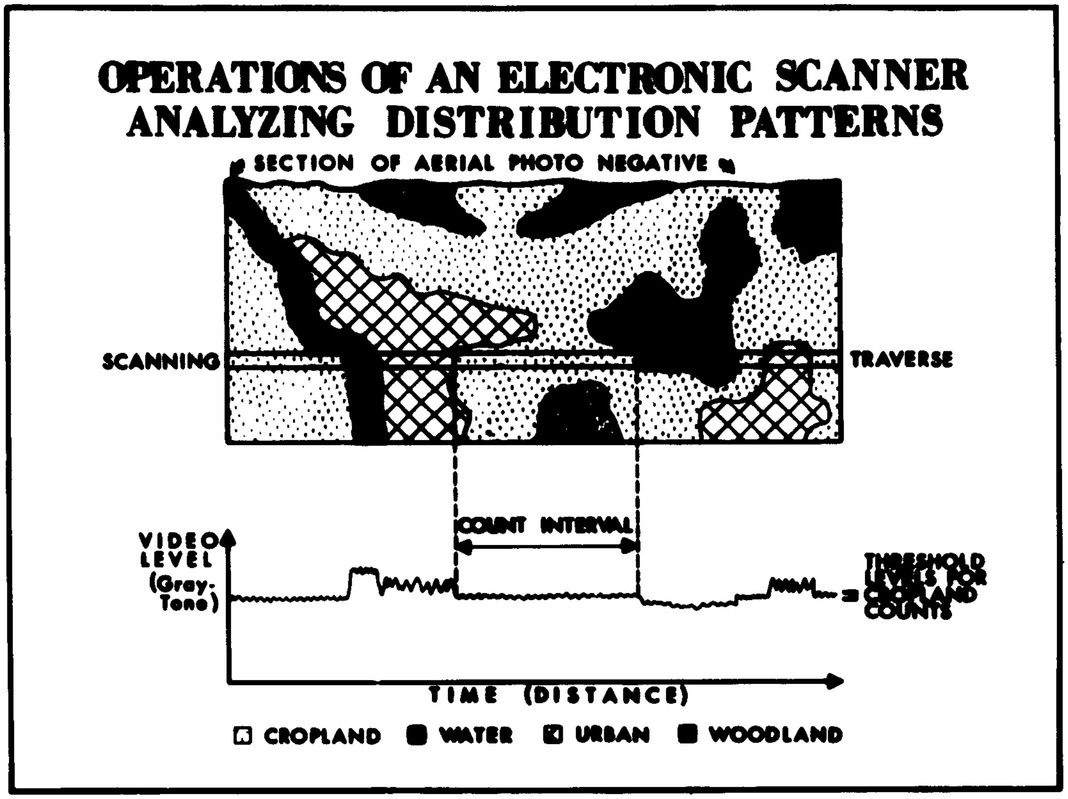


Fig. 13

as illustrated by Figure 13. It is feasible, for example, to so distinguish ice fragments, puddling, water surface, and some other aspects of artic sea ice photography; and laboratory demonstration has analyzed sea ice distribution by the use of scanners.[13] Other distinctly toned patterns, such as water surfaces, forested surface, beaches, cultivated fields, open pit mines, or cloud patterns are often identifiable by electronic scanners.

For more difficult phenomena such as urban areas, a texture analysis which evaluates both the overall average density (gray range) and the frequency with which contrasts of varying densities occurs within the film area has indicated considerable reliability.[14] Another possibility for segregating the particular patterns that one wishes to analyze with a scanner is offered by electronic image enhancement. Instruments can so emphasize particular gray tones, while fading their background, that a photograph of the enhanced picture would provide a negative which sufficiently differentiated the pattern of interest.[15] Although the reliability of gray tone for the identification of phenomena patterns is not yet adequate for the direct scanning and measurement of some photographic negatives, it is feasible to analyze the patterns with distinct contrasts that are available in some photography or available as a result of preprocessing for a scanner. Several agencies of government are now stimulating the investigation of this problem by electronic and photographic scientists. Rapid technological improvements can be anticipated.

Commercial scanners now available can count units of a distribution - such as lakes on land - without counting the same unit more than once although several traverses will intercept it.[16] With other scanners now being developed, the time it takes the flying spot to cross the surface unit (i.e.: the intercept distance) can be measured and then recorded in its proper length class. This measurement can be classified not only by length but also by gray tone of the phenomenon. The number of identifiable gray tone ranges, and the number of length classes which the scanner may distinguish will be largely a question of the funds available for the development of the machine. The output of the machine can be on display panels, punch cards, or tape suitable for computer processing. If needs justified the expenditure, automatic computer circuits can be built for the scanner and hence automatically perform statistical evaluation of the data. As the mechanical nature of the output devices would slow up the machine somewhat, it might take two or three minutes to accumulate the organized data from the scanning of a 9 by 9 aerial photograph or other distributions presented on film. Such data from a three thousand line scanning tube would be the result of automatic interpretation and measurement by 9 million sensor units.

For example, if any of the three sample regions in Figure 2 were presented to the scanner at the 1:2,000,000 scale of Figure 1, all data for one azimuth direction - such as that found in Table 1 - could be accumulated in three minutes, and it would be much more detailed since the sampling scanning lines would be at least 60 times as intense, and the measurement resolution would be over 8 times more precise.[17] Controlled rotation could test other azimuths. This comparison assumes that human measurement would be as precise as that of the machine, an unlikely assumption. Furthermore, the information could be available in a form which would permit direct introduction into a computer for statistical analysis.

In Conclusion

Quantitative analysis of complex geographic patterns can be accomplished by the Rotated Parallel Traverses Method. A pattern may be quantitatively described by tabular, statistical, or graphical presentations. Aspects of a phenomenon's size, shape, orientation, extension, fragmentation, dispersion, area occuppied, and proportion of total area occuppied can be determined and quantitatively described. The area of complexly extended surfaces can be measured. Patterns produced by the same phenomenon in different regions can be compared.

A quantitative comparison of the distribution may be utilized to study the space relations or inter-casual relations between physical, economic, social political, or military phenomena. Probable journey experience through a region may be quantitatively expressed.

The method lends itself to electronic instrumentation by the use of scanning devices which can identify, measure, sort, and count intercepts with differentiated phenomena. Additional electronic circuits or computer processing can mathematically or statistically evaluate the data. Such electronic measurement and processing can be completed in a few minutes. Electronic instrumentation of this geographic analysis can make economically feasible the rigorous evaluation and comparison of many stable patterns of distribution. It can also analyze dynamic patterns rapidly enough to include quantitative distribution data in systems designed to predict rapidly changing conditions of areal phenomena's distribution.

Notes

1. James, P. E. and Jones, C. F. (eds.) American Geography - Inventory and Prospect, Syracuse University Press, 1954, p. 7.

2. The "Cropland Areas in Pennsylvania" presented in Figure 1 have been extracted from the manuscript map "Land Use Categories in Pennsylvania". They were mapped by this writer and others working under the direction of Dr. Lester E. Klimm, who was Principal Investigator for Office of Naval Research Project (NR 389-055) completed at the University of Pennsylvania. Six categories of land use areas, one-quarter mile in minimum dimension, were determined by interpretation of the 1:20,000 aerial photographs, then mapped initially at 1:62,500, and finally compiled at the scale of 1:250,000. Figure 1 is approximately 1:2,000,000. Figure 1 is the first publication of a realistic land use pattern for such a large area of the United States.

3. The displayed regions have been selected for demonstration purposes from the forty-seven regions into which the total cropland distribution of Pennsylvania was organized by a rigorous application of "The D-line Method", which regionalizes complex patterns according to the distance relations of the distributant. See Lester E. Klimm, "Regional Description Based on Texture and Pattern of Unit Areas" (Abstract), Annals of the A. A. G., Vol. 46 (September, 1956), p. 256; and James P. Latham, "The Distance Relations of Cropland Areas in Pennsylvania" (Abstract), Annals of the A. A. G., (September, 1958), p. 277. For a complete demonstration of the D-line Method and also of the Rotated Parallel Traverses Method see James P. Latham, The Distance Relations and Some Other Characteristics of Cropland Areas in Pennsylvania: An Experiment in Methodology --, Technical Report No. 4, NR 389-055, Office of Naval Research, October 1958. (Also available on microfilm from University Microfilms, Inc., Ann Arbor, Michigan.)

4. See Joseph M. Trefethen, "A Method for Geographic Surveying", American Journal of Science, XXXII, Series 5 (December, 1936), pp. 454-464; also Malcolm J. Proudfoot, "Sampling with Traverse-Lines", Journal of the American Statistical Association, XXXVI (June, 1942), pp. 265-270.

5. It was found advantageous to make a large contact negative from the template of drawn traverse lines and then perform all measurements along the transparent lines in the opaque template thus created.

6. An orientation rose is not shown for the one region which contained no cropland and for those three small regions that contained such few occurences of cropland that some azimuths did not have enough intercepts to establish sampling validity. At the

scale of analysis applied, the cropland in the latter three is of little significance. A larger scale of analysis which sampled with more closely spaced traverses could establish validity by sufficiently increasing the number of intercepts.

7. Trefethen, op. cit., page 456.

8. Proudfoot, op. cit., page 267.

9. Ibid., page 268.

10. W. Allen Wallis and Harry V. Roberts, Statistics, a New Approach, Glencoe, Illinois: The Free Press, 1956, page 230.

11. For an interesting review of the history and methods of area measurement see: Malcolm J. Proudfoot, Measurement of Geographic Areas, Department of Commerce, Bureau of the Census (Washington: U.S. Government Printing Office, 1946).

12. For more complete information, see the following report by this author: Possible Applications of Electronic Scanning and Computer Devices to the Analysis of Geographic Phenomena, Technical Report No. 1, NR 387-023, Geography Branch, Office of Naval Research, 31 August 1959.

13. Geza Teleki, "Aerial Photography and Sea-Ice Forecasting" Naval Research Reviews, March, 1960, pp. 1-8. Also Robert Cook, "The Sea-Ice Photo-Interpretation Console", paper presented at Annual Meeting of Association of American Geographers, Miami Beach, April 23, 1962.

14. Azriel Rosenfeld, "Automatic Recognition of Basic Terrain Types From Aerial Photographs", paper presented at the m Military Electronics Convention, Washington, D. C., 28 June 1961, and published by Budd Electronics, Inc., 1961.

15. J. F. Baumunk, R. L. Hallows, and J. P. Smith, "Imagery Simulation and Enhancement", published by Astro-Electronics Division, RCA, Princeton, New Jersey, 1961.

16. H. P. Mansberg, "Automatic Particle and Bacterial Colony Counter", Science, Vol. 126, No. 3278 (Oct. 25, 1957), pp. 823-827.

17. Because manual measurements were made on a pattern scaled at 1:500,000 with traverses one-quarter inch apart (two miles), and length measurements made at one-thirty-second of an inch (one-quarter of a mile). The micron sized flying spot is one-thousandth of an inch. At 1:2,000,000 scale, scanning lines and units along line would have width equivalent to .031 mile.

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